Characterisation of the interior structures and atmospheres of multiplanetary systems

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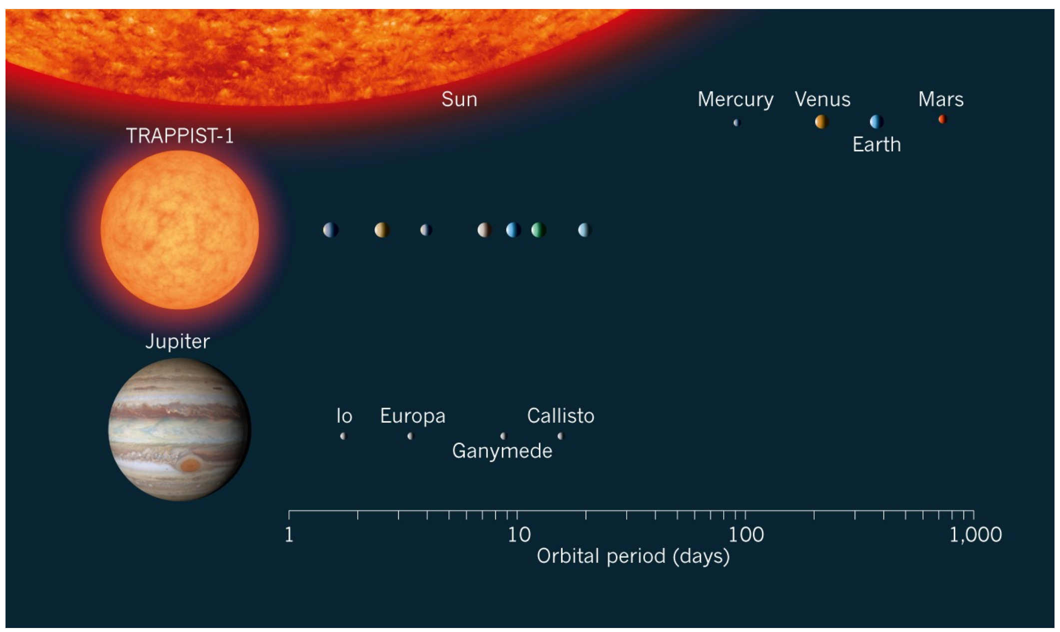
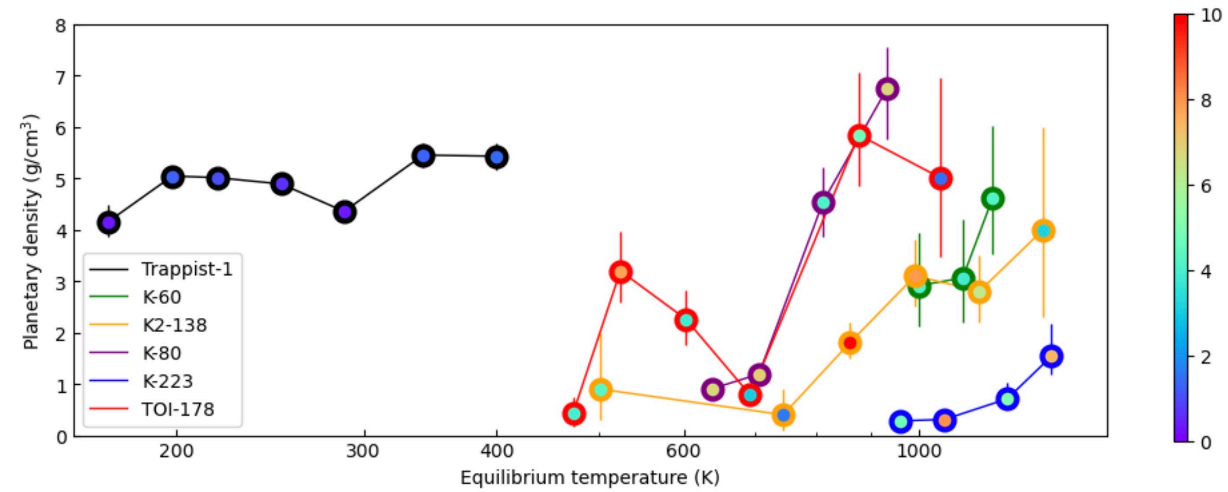
Introduction

- TRAPPIST-1 (Acuña+ 21, Agol+ 20), TOI-178 (Leleu+ 21):





Leleu+ 21

- Multiplanetary systems are environments suitable to explore the compositional diversity of low-mass planets, their formation and evolution

Interior structure model

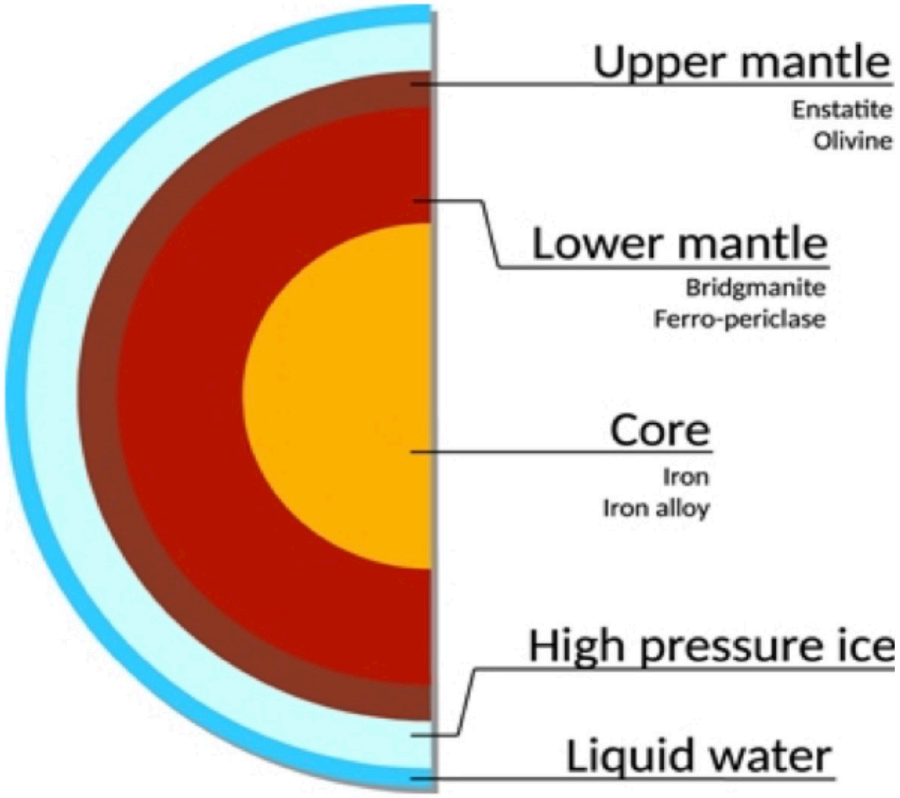
Mass

Core Mass Fraction (CMF)

Water Mass Fraction (WMF)

Surface pressure and temperature

→



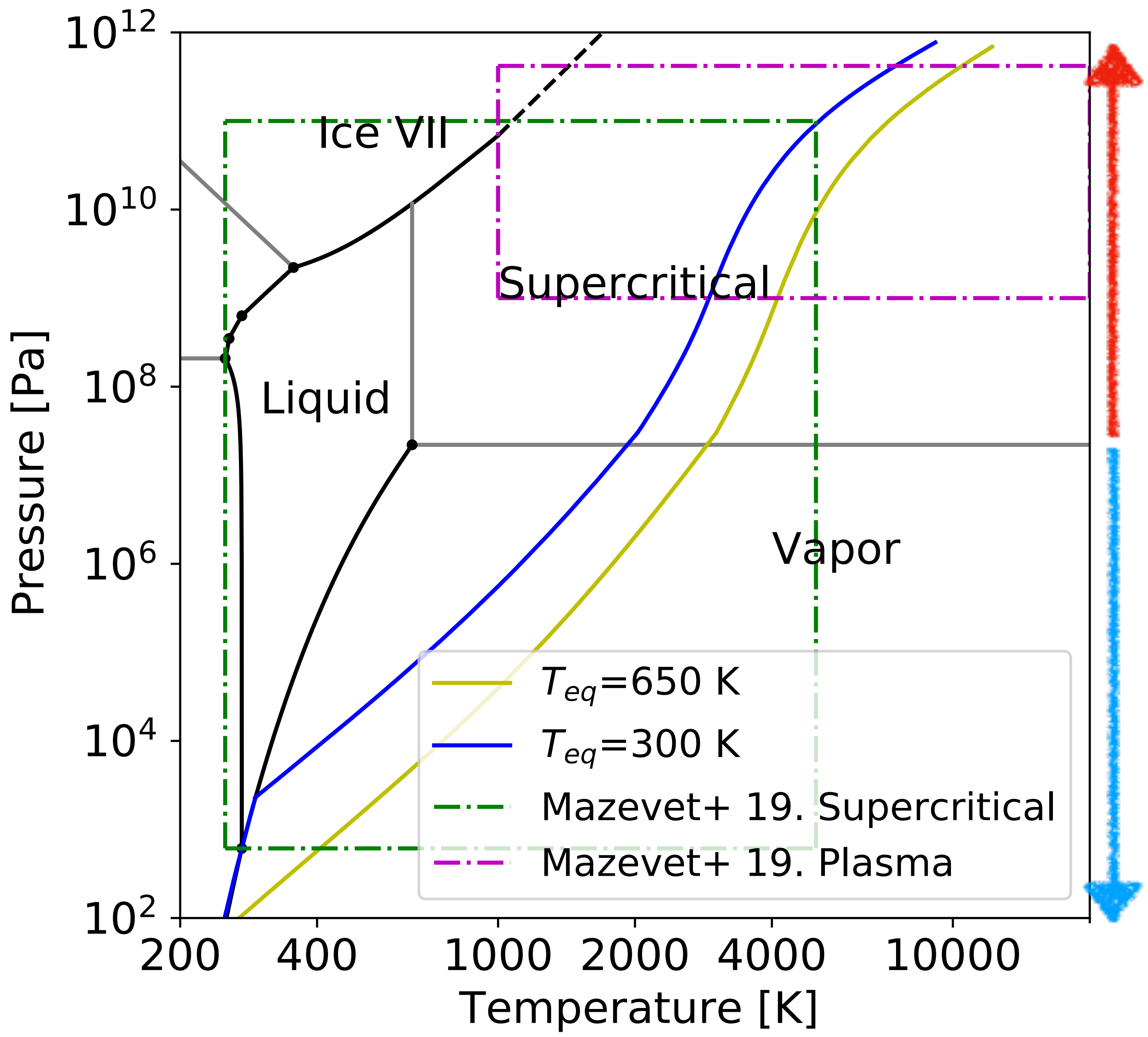
Brugger+ 17

→ Radius, Fe/Si

Pressure	$P(r)$
Gravity	$g(r)$
Temperature	$T(r)$
Density	$\rho(r)$

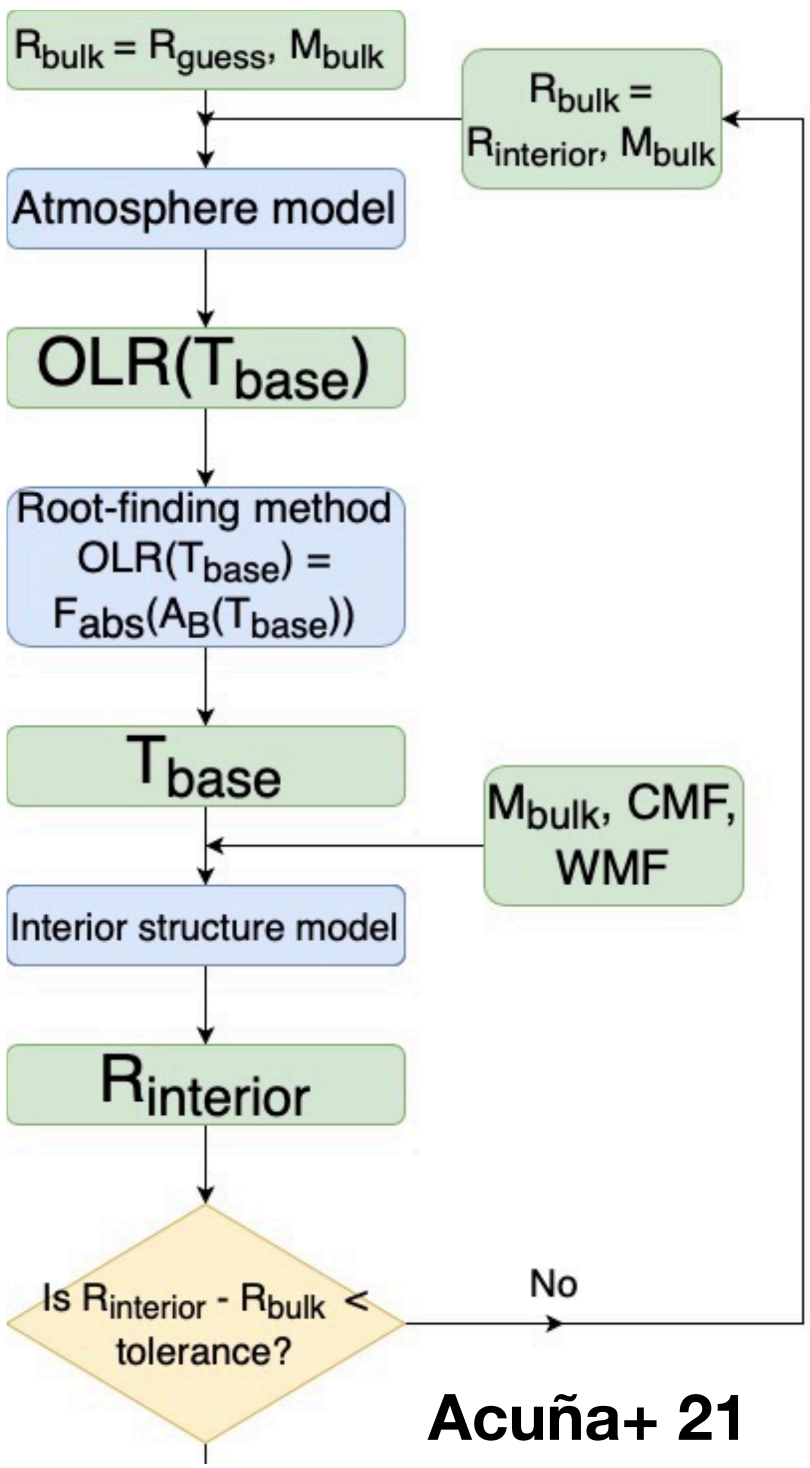
Interior-atmosphere coupling

- Water phase diagram:



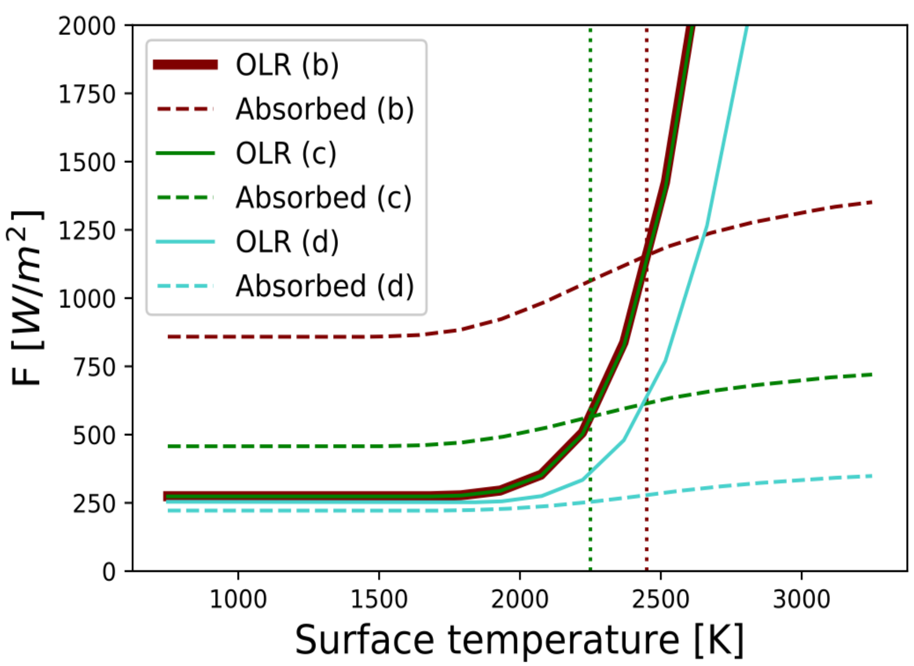
- Supercritical: Mousis+ 20. EOS from Mazevet+ 19
- Atmosphere model: Pluriel+19, Marcq+17

Interior-atmosphere coupling



Acuña+ 21

- Input: bulk mass and radius, T_{base}.
- Output: Outgoing Longwave Radiation (OLR), albedo, mass and thickness of atmosphere
- Radiative-convective equilibrium: $F_{abs} = OLR$

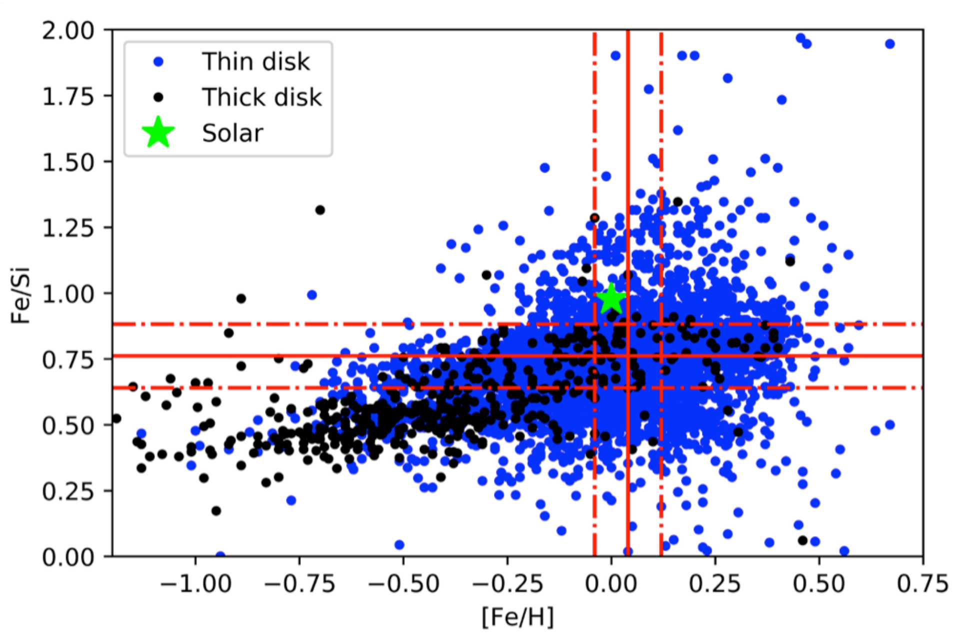


Acuña+ 21

Sample and MCMC

- Low-mass planets ($M < 20\ M_{\oplus}$)
- Systems with 5 or more planets

K2-138 (+ TRAPPIST-1 from
TOI-178 Acuña+ 21)
Kepler-11
Kepler-102
Kepler-80



Masses, radii and stellar abundances

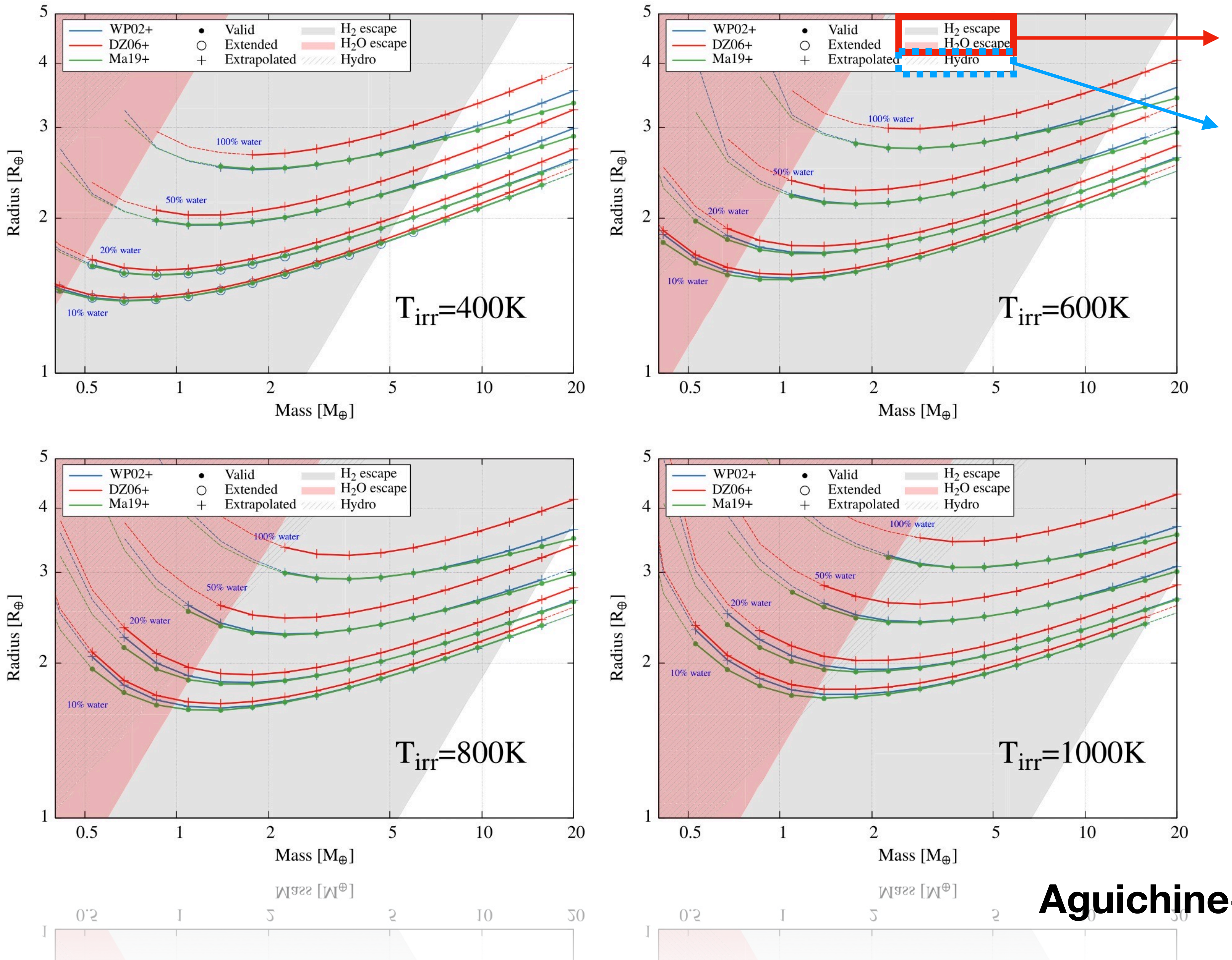
↓

MCMC Bayesian algorithm (Dorn+ 15, Acuña+ 21)

↓

WMF, CMF and atmospheric parameters

Atmospheric escape



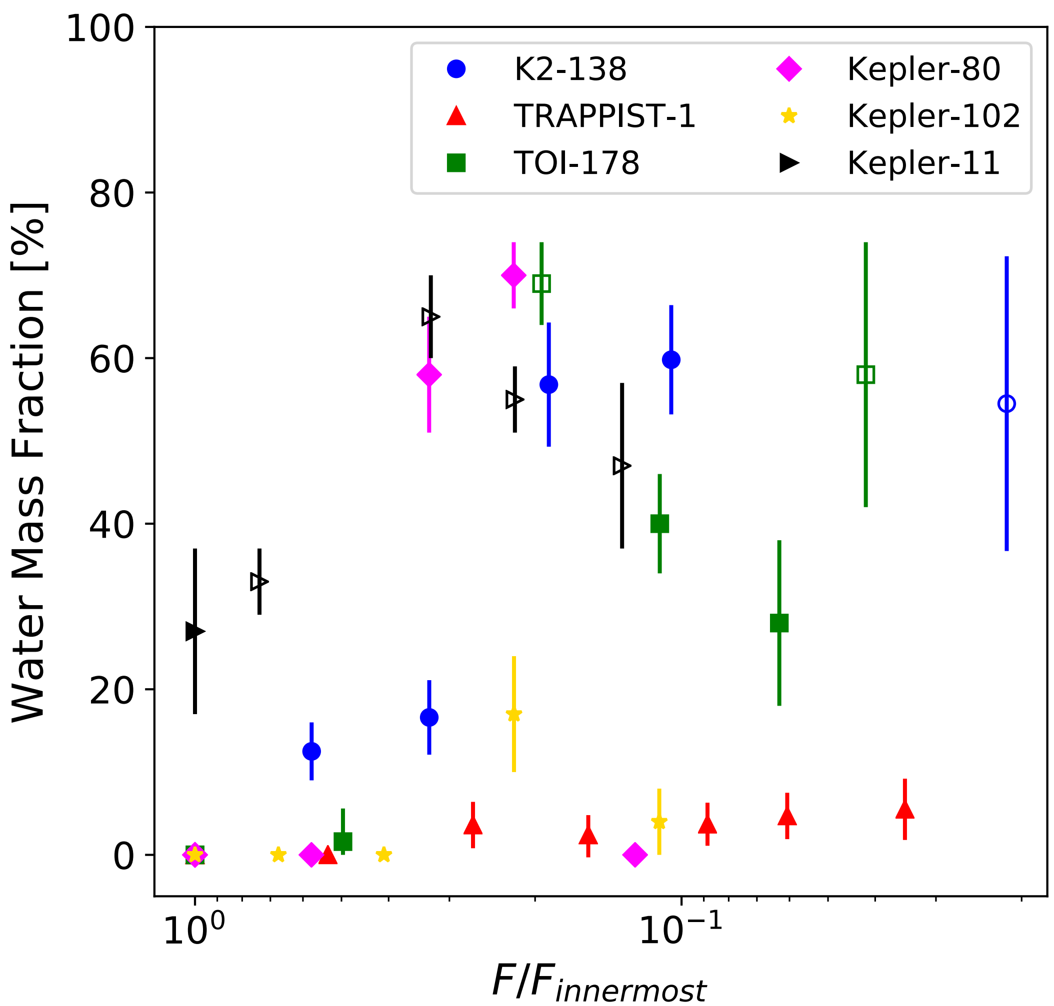
Jeans escape

Hydrodynamic escape

Aguichine+ 21

Results

WMF in multiplanetary systems



TRAPPIST-1 and K2-138:

Gradient + plateau trend

System	Planet	CMF	WMF	Significance	ΔM_{H2} [$M_\oplus$]
TOI-178	b	0.21±0.30	0	<1 σ	0.83
	c	0.30±0.02	$0.02^{+0.04}_{-0.02}$	<1 σ	< 0.01
	d	0.10±0.01	0.69±0.05	1.3 σ	0.16
	e	0.18±0.02	0.40±0.06	<1 σ	< 0.01
	f	0.22±0.03	0.28±0.10	<1 σ	< 0.01
	g	0.10±0.01	0.58±0.16	3.0 σ	< 0.01
Kepler-11	b	0.20±0.04	0.27±0.10	<1 σ	< 0.01
	c	0.18±0.01	0.33±0.04	1.7 σ	< 0.01
	d	0.10±0.02	0.65±0.05	2.4 σ	< 0.01
	e	0.12±0.01	0.55±0.04	4.4 σ	< 0.01
	f	0.14±0.06	0.47±0.10	1.9 σ	0.56
Kepler-102	b	$0.91^{+0.09}_{-0.16}$	0	<1 σ	0.13
	c	$0.95^{+0.05}_{-0.30}$	0	<1 σ	0.10
	d	0.80±0.14	0	<1 σ	< 0.01
	e	0.22±0.02	0.17±0.07	<1 σ	0.01
	f	0.27±0.09	0.04±0.04	<1 σ	0.02
Kepler-80	d	$0.97^{+0.03}_{-0.05}$	0	<1 σ	< 0.01
	e	0.43±0.18	0	<1 σ	< 0.01
	b	0.13±0.02	0.58±0.07	<1 σ	< 0.01
	c	0.09±0.01	0.70±0.04	<1 σ	< 0.01
	g	0.31±0.02	$< 1.5 \times 10^{-3}$	<1 σ	140

Trend deviations case by case

Conclusion

- Our **interior structure model** can be applied to low-mass planets at a **wide range of irradiations.**
- We obtain a clear **increasing water content with distance from host star + a plateau** for two multiplanetary systems.
- This trend could be shaped by **atmospheric escape**, **migration** type I and pebble accretion in the **vicinity of the ice line.**
- We analyse case-by-case those planets that do not fit the trend. We are able to explain these cases with either **Jeans atmospheric escape, H/He envelopes or high-CMF forming processes**, such as mantle evaporation, collisions or formation in the vicinity of the rocklines.

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